Research Note

NORTHERN ROCKY MOUNTAIN
FOREST AND RANGE EXPERIMENT STATION

Missoula, Montana

No. 31 November 9, 1943

THE APPLICATION OF SAMPLE LOG SCALING IN REGION ONE

by
Lawrence W. Zach, Junior Forester
Northern Rocky Mountain Forest & Range Experiment Station

ANALYSIS OF SAMPLE LOG SCALING FOR APPLICATION IN REGION ONE

Since the theory of sampling in regard to sample log scaling has been explained in detail by a number of writers, the writer has made no attempt to enlarge upon this field and has employed only such testing of data and formulae that appeared necessary to establish a basis for analyzing Region One conditions. The writer found the following authors of interest and profit in the field of sample scaling:

1. Lexen, Bert. Short Cutting the Scaling Job. The Timberman, Vol. XLIV, No. 9, 20-30, July 1943.

2. __________ The Application of Sampling to Log Scaling. Journal of Forestry, Vol. 39, No. 7, 624-631, July 1941.

3. Gevorkiantz, S. R. and Ochsner, H. E. A Method of Sample Scaling. Journal of Forestry, Vol. 41, No. 6, 436-439, June 1943.

4. Fogh, I. F. Sampling Methods in Log Scaling. Forestry Chronicle, 127-138, June 1943.

Reliability of an estimate based on sampling depends on the size of the sample, uniformity of the universe (unit of logs to be scaled) and distribution of sample units. These items impose certain restrictions or minimum requirements in order to arrive at theoretically reliable estimates of the volume of a unit of logs.

The formula $Sa = \frac{S}{\sqrt{N}}$ is used to give the standard error (a measure of reliability) if the standard deviation (a measure of variation between units in the universe) and number of sample logs are known or to give the number of sample logs necessary when the standard deviation and average size of log are known and the required reliability is given.

Where Sa = the standard error
S = the standard deviation
N = number of sample logs

Standard error in our case should be expressed in percent of the total volume of the logs to be scaled. It is a figure which we agree in advance to accept as a not unreasonable departure from the true log scale we would obtain if we scaled every log. It means that in two out of three volume estimates derived by measuring a definite number of logs (N) the estimate will not be greater or less than the true volume of all the logs by more than the standard error, say $2\frac{1}{2}$ percent. It also means that this estimate will not be greater or less than the true volume by more than twice the standard error in 20 out of 21 times. Hence if sample scaling is to be used, some standard error such as $2\frac{1}{2}$ percent must be agreed upon in advance.

The only difficult item to obtain for the use of the formula $Sa = \frac{S}{\sqrt{N}}$ is the standard deviation. A precise standard deviation requires an arithmetical calculation that is not difficult but is somewhat lengthy. Lexen has developed a rule of thumb for obtaining a usable approximation of standard deviation, which consists of dividing the range between the largest and smallest log by six. In order to check this rule of thumb for Region One conditions, it was applied to a timber sale on the Coeur d'Alene National Forest where the log size varied from 0 board feet (cull logs) to 1,780 board feet. The average size log was 172 board feet. Lexen's rule of thumb gives a standard deviation of $\frac{1,780 - 0}{6}$ or 297 board feet. The more precise standard deviation from the arithmetical calculation was 165 board feet. This indicates that Lexen's rule of thumb should be used with caution where a range in log size is as great and the average log as small as found on some operations in Region One. Subsequent investigation indicated that this operation had as great a range in log volume in comparison to average log size as any operation in the region.

Lexen has also developed an alignment chart[1/] for determining the intensity of sampling required with a given standard error and the unit of logs to be scaled. Use of this chart eliminates the need of determining the standard deviation; all that is required is the desired standard error and the total number of logs to be scaled. By using the formula $Sa = \frac{S}{\sqrt{N}}$ on the timber sale given in the paragraph above to calculate the standard errors for various sampling intensities, Lexen's chart was checked for Region One long logs. It was found that Lexen's standard errors are somewhat low for the long log operations but are reliable for short logs. In order to provide an alignment chart that could be used on long logs in Region One, the writer adjusted Lexen's chart on the basis of the logs from this timber sale on the Coeur d'Alene National Forest. Figure 1 gives Lexen's chart adjusted for use with long logs. Table 1 gives the comparison of the calculated standard errors, the standard errors from Lexen's chart and the standard errors from Lexen's chart adjusted for long logs for various sampling intensities on this timber sale.

1/ See chart in The Timberman, Vol. XLIV, No. 9, page 23, July 1943.

Fig. 1

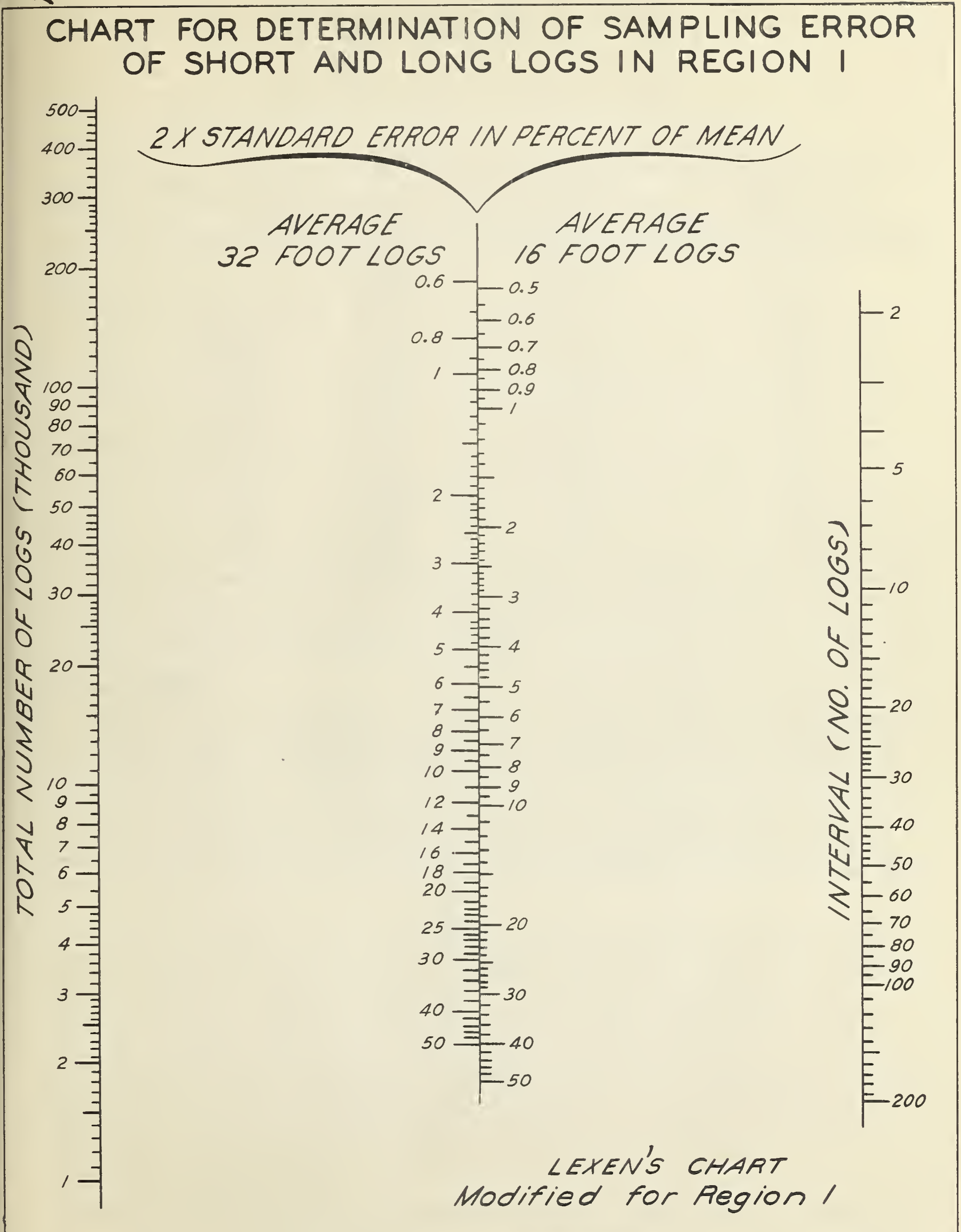
CHART FOR DETERMINATION OF SAMPLING ERROR
OF SHORT AND LONG LOGS IN REGION I
TOTAL NUMBER OF LOGS (THOUSAND)
500 400 300 200 100 90 80 70 60 50 40 30 20 10 9 8 7 6 5 4 3 2 1
2 X STANDARD ERROR IN PERCENT OF MEAN
AVERAGE
32 FOOT LOGS
0.6 0.8 1 2 3 4 5 6 7 8 9 10 12 14 16 18 20 25 30 40 50
AVERAGE
16 FOOT LOGS
0.5 0.6 0.7 0.8 0.9 1 2 3 4 5 6 7 8 9 10 20 30 40 50
INTERVAL (NO. OF LOGS)
2 5 10 20 30 40 50 60 70 80 90 100 200
LEXEN'S CHART
Modified for Region I

Table 1. - Expected reliability of log sampling in long log production in Region One

(Based on 66,600 white pine logs cut on the Coeur d'Alene National Forest - 1942)

Log interval	Total number sample logs	Calculated 1x standard error	Lexen's alignment chart 1x standard error (average 16-ft.logs)	Adjusted alignment chart 1x standard error (average 32-ft.logs)
		Percent	Percent	Percent
5	13,320	0.83	0.70	0.85
10	6,660	1.18	0.97	1.20
20	3,330	1.66	1.40	1.70
45	1,480	2.50	2.10	2.50
50	1,332	2.63	2.20	2.70
75	888	3.22	2.70	3.25
100	666	3.72	3.10	3.75
200	330	5.28	4.35	5.25
333	200	6.79	-	-

MINIMUM REQUIREMENTS FOR SAMPLE LOG SCALING

Size of Sample

In reference to the minimum number of logs necessary to meet sampling requirements Lexen makes the following statement: "Assuming 5 percent a maximum acceptable limit for twice the standard error of the mean and neglecting the small correction for a limited population, 1,000 logs must be scaled in order to insure an acceptable estimate of total volume. If scaling more than approximately every fifth log results in only a small saving of time over complete scaling, 5,000 would be about the lowest number of logs to which sampling scaling can be effectively applied."

There could be cases where a saving might still be realized by scaling more than every fifth log, but the important fact is that 1,000 logs is the minimum size sample required to give an estimate within 2.5 percent (one standard error) of the true volume 2 times out of 3 or within 5 percent (two times standard error) of the true volume 20 out of 21 times. This limit of error is true for single-length logs in Region One as well as for the logs used by Lexen. For double-length logs about 1,500 is the minimum size sample that will assure the same reliability of estimate attained by 1,000 short logs. This can be verified by referring to figure 1 and table 1. More long logs are required for a minimum size sample because of the wider range in log volume.

Uniformity of the Universe

In Region One there are two factors that lend heterogeneity to the universe or

unit of logs to be scaled; viz., range in log size and mixture of tree species resulting in more than one stumpage price.

Range in log size varies from cull logs of no salable volume to long (double-length, average 32 foot) logs of about 1,800 board feet. Very few logs will be found to exceed this maximum. Long logs are a potent factor in stepping up the range in log volumes. For instance, the maximum size long log of 1,800 board feet on a short (average 16 foot) log operation would be cut into two short logs of about 800 and 1,000 board feet; hence, the range in log size would be 0 to 1,000 board feet instead of 0 to 1,800 as is now the case. The close utilization of western white pine further accents the standard deviation already large because of the wide range in log volumes by lowering the size of the average log. Hence Lexen's chart requires adjustment for reliable application to long log operations since standard deviation is a test of uniformity; therefore, larger samples are needed for Region One long logs with their greater standard deviation.

The other factor affecting uniformity of the log unit is the series of stumpage prices on a mixed timber operation. On a timber sale where more than one species is being cut, each species or combination of species selling for the same stumpage price theoretically must be treated as a separate universe or unit in applying minimum requirements of sample sizes for each species. Subsequent data show that other factors modify this requirement. To demonstrate these requirements we may assume a sale of 15,000 short logs composed of 5,000 fir and larch, 5,000 spruce and 5,000 ponderosa pine. According to the alignment chart, one standard error of 2.5 percent requires scaling every fifth log to give the required reliability. This assumed case is still simple although some of the savings from sampling has already been lost; if all the logs were of one species or one stumpage price, only 1 log in 15 would require scaling in order to secure the reliability of estimate secured with the first assumption. Now to complicate the case further, assume a sale of 1,000 ponderosa pine logs, 9,000 fir and larch logs and 5,000 spruce logs. In order to fulfill sampling requirements, all the ponderosa pine logs would require scaling. Obviously in theory the number of logs of each species in a mixed sale must be at least large enough to meet minimum sampling requirements.

Theoretically the last assumed unit of logs might be adequately sampled by scaling every pine log, every tenth fir and larch log and every fifth spruce log. The result would be the same as sampling three different units of logs with a separate log count for each species. In practice this approach was found to lead to confusion because of the multiple sampling intervals and log counts. For successful sampling, procedures must be simple enough to allow the average scaler to apply the method without making serious blunders.

Distribution of Samples

There is general agreement that representative sampling is obtained in sample log scaling by random sampling or through selection of samples by a mechanical interval. Furthermore, mechanical sampling is recommended as the simplest method and is preferred for practical use in sample log scaling. The more uniformly the samples are spaced throughout the unit, the better are the chances of a reliable estimate.

Aside from species composition, minimum size samples and values involved, a requirement for practical application of sample scaling is the necessity of

having logs present in quantities and in a position for efficient sampling. Logging methods on operations of any consequence in Region One are almost without exception what is known as hot logging; that is logs do not accumulate or remain in any one location for an appreciable period of time. The seasonal character and methods of logging require getting logs out during the open season as fast as possible and they are cut, skidded, loaded and delivered into the mill pond in a comparatively short period of time. Skidding, loading and hauling is carried out currently at a number of points in the woods at the same time. What few logs may accumulate are usually jackpotted or so poorly decked that scaling in decks is impractical.

The actual task of scaling under the conditions and methods in use in Region One usually creates a bottleneck which slows up the steady flow of logs and adds additional handicaps to the logging operator. In some instances it has been necessary for the operator to prepare a suitable landing at considerable extra expense to enable the Forest Service to obtain any kind of an adequate scale. Additional attempts to provide landings where logs can be accumulated in sufficient quantities and spread out in position suitable for practical sampling may further increase the handicap to the operator.

Present practice is to scale logs at such points where a minimum of operating time is lost and where scaling costs can still be held within reasonable limits. On the relatively small sales of Region One a scaler is usually stationed at a loader or a landing where logs are scaled in varying quantities. The hot logging requires the scaler's presence regardless of the quantity of logs passing the point of scaling. One scaler is obviously the minimum amount of manpower possible to employ at one point. Hence in hot logging where the volume of logs is such that the scaler can handle it with a 100-percent scale, there is no gain made by sampling even if the volume, species composition and position of logs were such as to make sampling practicable.

Accuracy Required

The degree of accuracy required is governed by the values involved based on the stumpage price. High value species would obviously warrant more intensive sampling to assure accurate estimates while low value material would require less precise volume determinations. Table 2 gives the possible loss or gain from various errors for the range of stumpage prices found in Region One.

Table 2. - Values involved from errors of estimate by percent of error and stumpage price

Stumpage price per M bd.ft.	1 percent error	2.5 percent error	5 percent error	10 percent error	25 percent error
$	$	$	$	$	$
	- - - - Loss or gain in dollars per M board feet - - - - -				
0.50	0.005	0.012	0.025	0.05	0.125
1.00	0.01	0.025	0.05	0.10	0.25
2.00	0.02	0.05	0.10	0.20	0.50
3.00	0.03	0.075	0.15	0.30	0.75
4.00	0.04	0.10	0.20	0.40	1.00
5.00	0.05	0.125	0.25	0.50	1.25
5.65	0.06	0.14	0.28	0.565	1.41
8.00	0.08	0.20	0.40	0.80	2.00
10.00	0.10	0.25	0.50	1.00	2.50
12.00	0.12	0.30	0.60	1.20	3.00

The values involved as shown in table 2 will influence the intensity of sampling. For instance a sale of timber at $4 per thousand board feet with a scaling cost of 10 to 12 cents for a 100-percent scale would justify sampling intensively enough to give an error of less than 2.5 percent or 10 cents per thousand. Otherwise either the buyer or the seller would lose almost the cost of a 100-percent scale.

An accurate count of the total number of logs in the unit of logs to be sampled is imperative regardless of the method or the intensity of sampling. An inaccurate log count introduces an immeasurable error that would make any estimates questionable.

To demonstrate the behavior of species composition in sampling as species occur in Region One, several typical cases are given. Table 3 (concerned with the same data as table 1) gives the results on an operation cutting a single species at a stumpage price of $5.65 per thousand board feet. Referring to tables 1 and 2, a 2.5 percent error would require scaling 1 log in 45 and would involve a loss or gain of 14 cents per thousand. By increasing the number of logs to be scaled to 1 log in 10, the one times standard error is reduced to 1.18 percent, which involves 6-2/3 cents per thousand board feet loss or gain if the estimate is in error as much as one standard error.

Table 3. - Comparison of estimated and actual volume and values involved through errors of estimate in sample scaling

(Based on cut of 66,600 white pine logs - average 32 feet Coeur d'Alene National Forest - 1942. Stumpage price $5.65 per M board feet - scaling every tenth log)

Scale book	Total number logs	Number sample logs	Actual volume	Estimated volume	Deviation	Deviation	Loss or gain per M bd.ft.	Total loss or gain
			Bd. ft.	Bd. ft.	Bd.ft.	Percent	$	$
B	10,000	1,000	2,072,240	2,106,600	+34,360	+1.66	+.094	+194.13
C	10,000	1,000	1,501,510	1,509,400	+ 7,890	+0.53	+.030	+ 44.58
H	9,100	910	1,448,320	1,399,100	-49,220	-3.40	-.192	-278.09
88	10,000	1,000	1,686,300	1,673,900	-12,400	-0.74	-.042	- 70.06
89	10,000	1,000	1,692,310	1,674,600	-17,710	-1.05	-.059	-100.06
90	7,500	750	1,339,790	1,300,700	-39,090	-2.92	-.165	-220.86
91	10,000	1,000	1,713,370	1,742,400	+29,030	+1.69	+.096	+164.02
Total	66,600	6,660	11,453,840	11,406,700	-47,140	-0.41	-.023	-266.34

The total value of the 66,600 logs is $64,714.20. The deviation (-0.41 percent) resulting from sample scaling every tenth log would amount to a loss to the Government of $266.34 out of a total value of $64,714.20 or at the rate of 2-1/3 cents per thousand board feet. If an error of one standard deviation (calculated as 1.18 percent) had occurred, the deviation would have been $763.63 or 6-2/3 cents per thousand. However, it must be borne in mind that in setting up a sample scaling job the expectation for the sale in table 3 is that 2 times out of 3 the deviation would be not more than 1.18 percent in error (6-2/3 cents per thousand) but once out of three times the error could be expected to be greater than 1.18 percent. The very close estimate of -0.41 is better than can be hoped for under the given conditions. The deviation by scale books indicates something of how errors compensate as the universe and hence the size of sample (same intensity of sampling) increases in size.

Table 4 is the scale and sampling of a sale on the Kootenai National Forest. It is a typical example of a larger mixed species, long log sale in Region One.

Table 4. - Losses and gains from large errors of estimates due to small samples of separate species and effect on total log volume and value

(Based on cut of 31,321 logs, average 32 feet, of mixed species Kootenai National Forest - 1940. Scaling every tenth log)

Species	Total number logs	Actual volume	Deviation from actual volume	Deviation	Loss or gain per M bd.ft.	Total loss or gain	Stumpage price per M bd.ft.
		Bd.ft.	Bd. ft.	Percent	$	$	$
Western white pine	21,493	5,163,870	+34,930	+0.68	+0.043	+223.55	6.40
Ponderosa pine	1,000	332,570	-19,170	-5.76	-0.156	- 51.76	2.70
Larch-Douglas-fir	1,099	350,630	+63,970	+18.24	+0.182	+ 63.97	1.00
Engelmann spruce	1,934	568,800	-10,400	-1.83	-0.032	- 18.20	1.75
Western hemlock	5,795	629,130	-10,830	-1.72	-0.009	- 5.42	.50
All species	31,321	7,045,000	+58,500	+0.83	+0.030	+212.14	

Here is a case of six species sold at five separate prices. The number of logs of ponderosa pine, fir and larch, and spruce are too small to meet minimum sapling requirements for any reasonable degree of reliability. The alignment chart gives an expected reliability of one standard error of ± 1.7 percent for the total of all species. Deviation is about one-half this one standard error. If errors of estimate had approached one standard error with errors by species in the same proportion as in table 4, the gain to the Government would have been about 6 cents per thousand board feet or about $450. The total stumpage value was $35,605.25.

Common sense dictates that failure to meet minimum sampling requirements by species is not necessarily a serious matter where requirements are met for the total unit of all species as indicated in table 4. Here the predominant species is also the high value one and can meet minimum requirements. However, in cases where the high value species make up a small part of the total volume, the values involved and less reliable estimates expected from the small units would make the results questionable. Obviously, where the range in stumpage price is small, the deviation by species within the total unit of all species is of less significance. Such a case is demonstrated by table 5 giving a sale of mixed species on the Lolo National Forest where two sets of samples were taken. Here the stumpage price was $2 per thousand board feet for ponderosa pine and $1.50 per thousand for all other species. The one times standard error on Lexen's alignment chart (16-foot logs) for a sampling interval of 5 is 2.3 percent for the total unit. Deviations in both cases are slightly greater than this, but estimates would probably be considered acceptable for the values involved. In the first sampling, the stumpage price paid the Government would have been $34.90 or less than 4 cents per thousand board feet too low, while in the second sampling the stumpage price would have been $39.07 or slightly over 4 cents per thousand too high.

Table 5. - Losses and gains from large errors of estimates due to small samples of separate species and effect on total log volume and value

(Based on cut of 6,047 logs, average 16 feet, of mixed species Lolo National Forest - 1935. Scaling every fifth log)

SAMPLE NO. 1

Species	Total number logs	Volume	Deviation from actual volume	Deviation	Loss or gain per M bd.ft.	Total loss or gain
		Bd.ft.	Bd. ft.	Percent	$	$
Douglas-fir	1,697	215,930	-6,580	-3.05	-0.046	-9.87
Western larch	2,811	490,960	-24,910	-5.07	-0.076	-37.36
Engelmann spruce	773	103,351	+4,799	+4.64	+0.070	+7.20
Lodgepole pine	166	10,630	+4,420	+41.58	+0.624	+6.63
Ponderosa pine	600	111,600	- 750	-0.67	-0.013	-1.50
Total	6,047	932,471	-23,021	-2.47	-0.037	-34.90

SAMPLE NO. 2

Species	Total number logs	Volume	Deviation from actual volume	Deviation	Loss or gain per M bd.ft.	Total loss or gain
Douglas-fir	1,697	215,930	-8,480	-3.93	-0.059	-12.72
Western larch	2,811	490,960	+30,890	+6.29	+0.094	+46.34
Engelmann spruce	773	103,351	-7,101	-6.87	-0.103	-10.65
Lodgepole pine	166	10,630	+3,870	+36.41	+0.546	+5.80
Ponderosa pine	600	111,600	+5,150	+4.61	+0.093	+10.30
Total	6,047	932,471	+24,329	+2.61	+0.042	+39.07

Summary of Sampling Requirements

There are four major requirements that must be met in Region One to make sample scaling practicable:

1. In order to obtain a standard error commensurate with the high value of some Region One species and great range in log size that will still give a saving in manpower, the minimum size unit of logs suitable for scaling is 8,500 short logs or 13,000 long logs. These units are assumed on the basis of scaling not more than every third log with a resulting standard error of 1.5 percent of the mean. For lower value species a standard error of 2.5 percent might be acceptable requiring a minimum size sample of 3,000 short logs or 4,800 long logs if every third log were scaled.

2. Where a unit of logs is composed of mixed species selling for appreciably different stumpage prices, each species or group of species

selling at one price should approach the minimum sampling requirements of (1) above. Since errors tend to compensate as shown in tables 4 and 5, minimum requirements by species are not as rigid as for a sale of a single species where compensating errors do not occur. Judgment must be exercised, however, when relaxing requirements for species within a mixed unit of logs. Other things being equal, the species of the smallest total volume in a mixed sale will have the greatest effect in setting the intensity of sampling necessary to meet its sampling requirements.

3. Logs must be present in quantities and in position for efficient sampling. A valid method of choosing samples must be adhered to. Such a method should preferably be mechanical and simple enough to be easily applied by the average scaler without undue chance of bias.

4. It is self-evident that an accurate count of the total number of logs is imperative for any sample scaling.

To summarize, sampling must result in estimates of the required reliability and must result in a saving of manpower or scaling costs or both.